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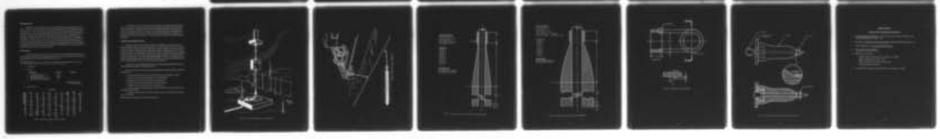

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# DESIGN AND FABRICATION OF TERMINATION BOOTS FOR MECHANICAL/ELECTROMECHANICAL CABLE TERMINATIONS

edited by

N. F. Johnson
OCEAN TECHNOLOGY DEPARTMENT
November 1976

NAVAL UNDERSEA CENTER
SAN DIEGO, CALIFORNIA

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Technical Director

## ADMINISTRATIVE STATEMENT

This work was performed under contract by Lane Instrument Company during the transitional Fiscal Year 1977T under joint Federal and State of California sponsorship of the Tethered Float Breakwater Program. Funding was provided under California Department of Navigation and Ocean Development Order Number 06-101275, Department of the Army Corp of Engineer Task E-N-76-10, Department of Commerce Maritime Administration Project Number 12-502-60-034 and Department of the Navy Naval Facilities Engineering Command Sub Project SL-XB-002.

This task was approved by the Tethered Float Breakwater Ocean Experiment Program Director Dr. R. J. Seymour, Staff Oceanographer California Department of Navigation and Ocean Development. The report was reviewed for technical adequacy by J. B. Berkley and edited by N. F. Johnson of this Center.

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>This report documents a design study conducted for the Naval Undersea Center by Lane Instrument Company. The study was conducted to develop a design of boots for control of the bending radius at wire rope terminations. This report also provides sufficient data to design and fabricate boots to user requirements. | |

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Lane Instrument Co. El Cajon, Calif.

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# SUMMARY

This report documents the design study performed by Lane Instrument Company of El Cajon, California under contract number N66001-76-M-V163. Lane Instrument Company was tasked to develop a design procedure for fabrication of mechanical and electromechanical cable termination boots for control of bending radius at the termination points.

This report is also intended to serve as a guide for design and fabrication of termination boots.

Presented herein are brief descriptions of the boot design, function, and present application and a comparison with other termination devices. Following this background information, boot design theory, design instructions and fabrication guidelines are provided. In addition, three complete design examples are provided.

# CONTENTS

# BACKGROUND

## GENERAL

Previous experience has shown that terminations of mechanical or electromechanical cables have very high failure rates in dynamic situations. One of the studies conducted for the Naval Undersea Center as part of the Tethered Float Breakwater (TFB) project addressed this problem. This study provided the design for a highly efficient wire rope termination boot. The boot restricts the bending radius of the wire at the termination to a safe radius for the size wire used.* The variables considered by the design are:

- Wire size (diameter)
- Minimum bend radius
- Working tension
- Maximum bending angle
- Modulus of boot material.

The minimum bend radius for a given.line must be determined by the user and is dependent of the type and size of line and the cycle life desired. The modulus of the wire is not a consideration since this "error" factor only tends to increase the bending radius.

Figures 1 and 2 depict the TFB wire termination boot. Figure 3 shows the typical failure mode of wire terminations that do not utilize boots.

## PREVIOUS BOOT INVESTIGATIONS

The only notable design studies previously conducted within the military establishment were by Wood's Hole Oceanographic Institution, Wood's Hole, Mass. These studies resulted in improved buoy systems using boots. However, these designs still suffer relatively high failure rates when subjected to dynamic system stresses, as in the Tethered Float Breakwater.

Industry has not produced any designs suited for long-term dynamic situations. Most boots on mechanical and electromechanical cable terminations are cosmetic and/or for leak-proofing. Many do, in fact, limit the bend radius, but they can not be considered efficient designs, since they do not consider the stresses encountered in a dynamic system.

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**The boot does not provide tensile support to the termination; it simply controls the bend radius of the cable to that which will minimize local work hardening.*

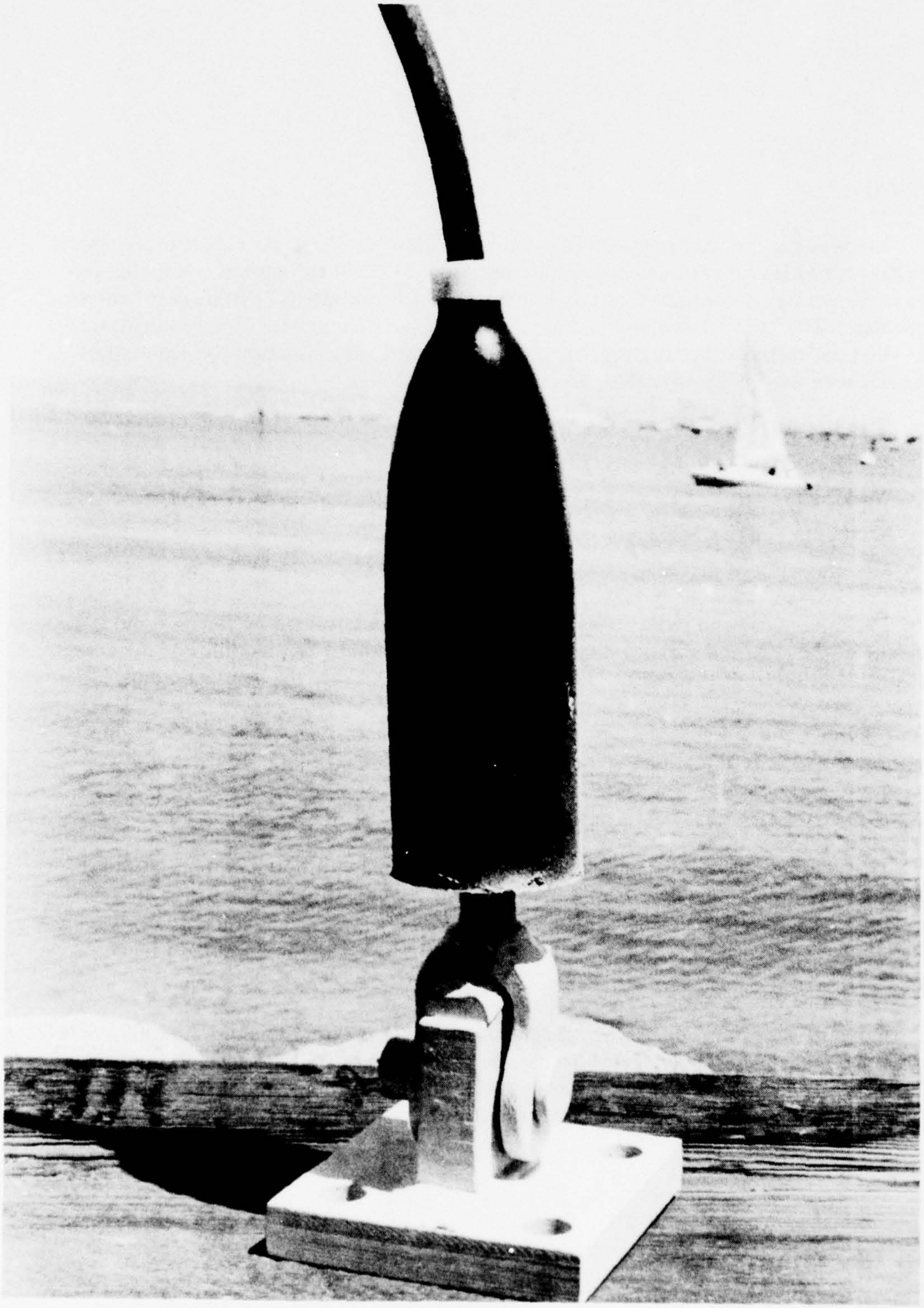


Figure 1. TFB wire termination boot.

DESIGN PARAMETERS

ROPE DIAMETER = 0.677"
MIN BEND RADIUS = 12"
TETHER TENSION = 3600-4400 lbs.
MAX TETHER ANGLE = 12"

X, Y COORDINATES

| X | Y (r) |
|---|---|
| .0 | 1.71 |
| .5 | 1.71 |
| 1.0 | 1.71 |
| 1.5 | 1.66 |
| 2.0 | 1.61 |
| 2.5 | 1.54 |
| 3.0 | 1.45 |
| 3.5 | 1.34 |
| 4.0 | 1.20 |
| 4.5 | 1.01 |
| 4.75 | 0.89 |
| 5.00 | 0.73 |
| 5.25 | 0.54 |

MATERIAL
POLYURETHANE ELASTOMER
CREAST #7343/7139*

E = 2810 PSI

NOTE: POLYURETHANES SHOULD BE ETHER BASED OR AMINE CURED. DO NOT USE ESTER BASE FOR SALT WATER.

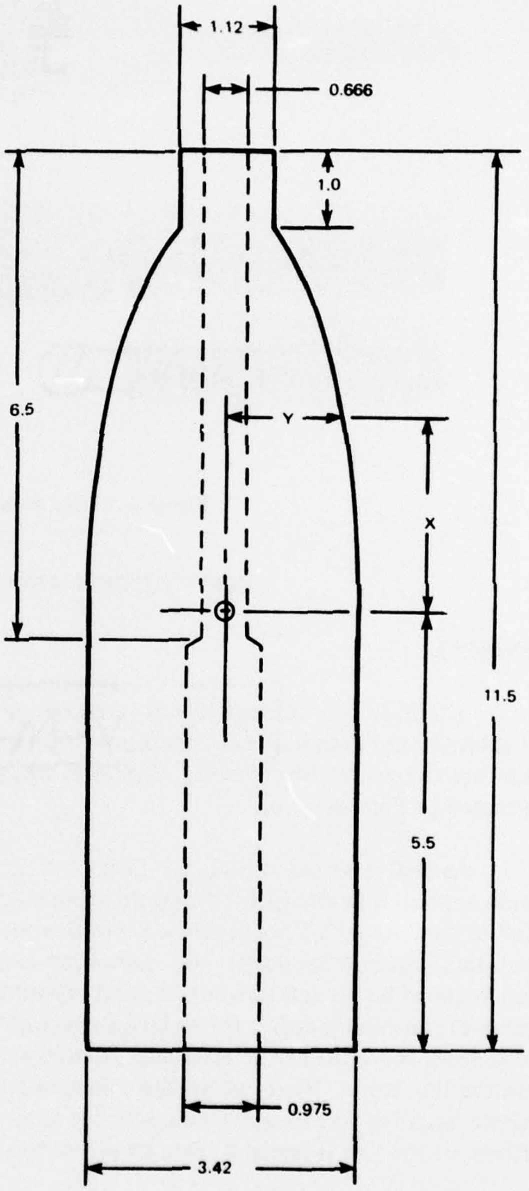


Figure 2. TFB wire termination boot configuration.

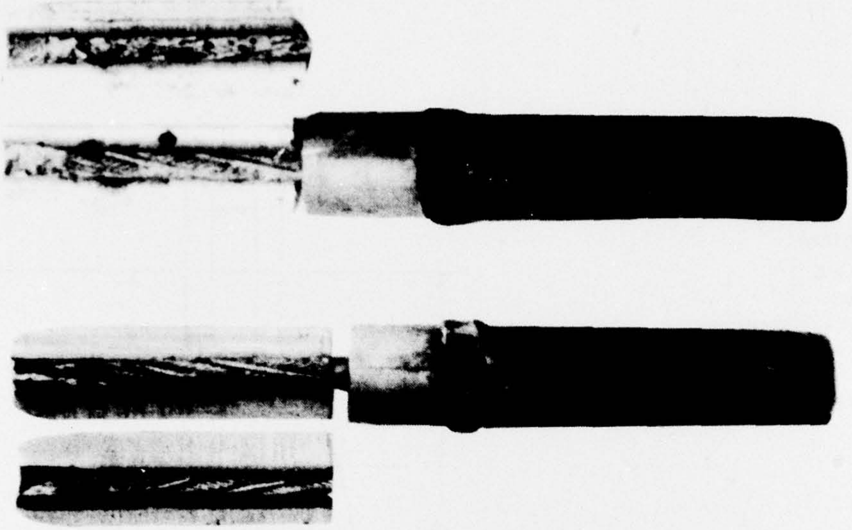


Figure 3. Failed wire terminations.

## BOOT DESIGN AND FABRICATION

### GENERAL

The following information is provided to aid users of mechanical and electromechanical cables in the design and fabrication of termination boots. The calculations described below are the results of the study work performed to develop the TFB termination boot illustrated in Figures 1 and 2.

As well as documenting the TFB boot design, the following paragraphs present a simple approach to design of a variable-beam sleeve (boot) to restrict the bending radius of a line or rope under a known tension and flexing through a known maximum angle. The input data required for design are: minimum bending radius, line radius, tensile force, maximum angle of bend, and tangent flexural modulus of elasticity of the boot material. The output of the calculation is the exterior envelope dimensions as described by x-y coordinates. The tangent modulus of the elastomer used in this study was calculated rather than drawn from the literature. Where literature values of flexural modulus for elastomers are used, the tangent modulus will be approximately 1.4 times the reported secant values. The flexural stiffness of the line is ignored since its effect would slightly reduce the envelope radii.

The shape of the boot is based on Bernoulli-Euler law for the bending of beams:

$$M = \frac{EI}{R_o} \qquad (1)$$

Where:

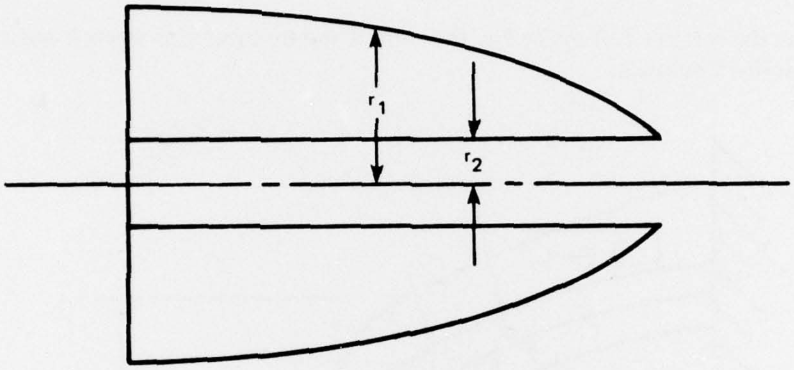
$I = \int y^2 dA,$

$R_o$ = bending radius,

$E$ = modulus of elasticity in flexure,

$M$ = moment in the beam.

For the case of a variable-beam boot with a circular cross section as shown below,



the moment of inertia at each cross section is:

$$I = \frac{4}{\pi}(r_1{}^4 - r_2{}^4) \tag{2}$$

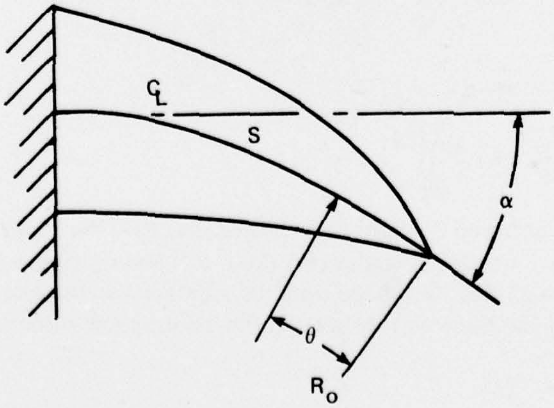
Where:

$I$ = moment of inertia,

$r_1$ = outside radius,

$r_2$ = inside radius.

Consider the boot surrounding a cable under tension and moving through an arc with the bending radius constant along the active length of the boot.



The minimum length of the boot at the center line is

$$S = \frac{2\,R_o\,\pi\,\alpha}{360} \tag{3}$$

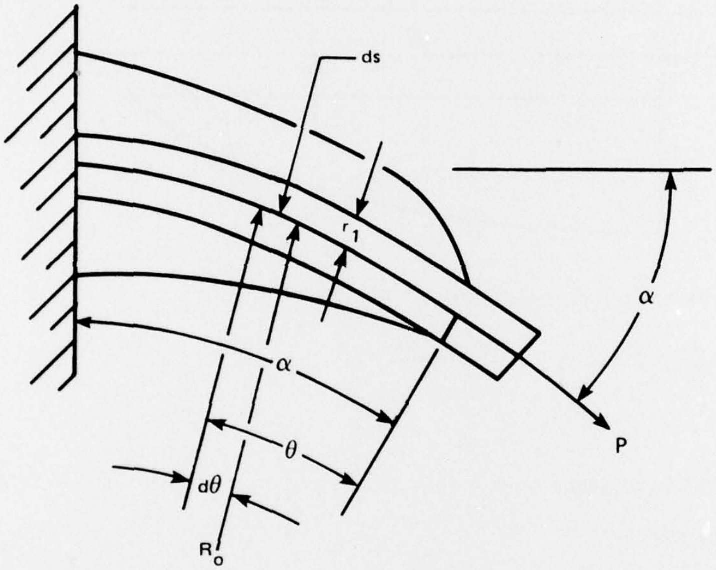
Where

$S$ = length along the arc,

$R_o$ = bending radius,

$\alpha$ = ∢ of bend of the tether.

The moment at the section defined at $\theta$ is the sum of the moments between $\theta$ and $\alpha$. The moments are defined below as:



$$M = \int_{\theta}^{\alpha} R_o\,P \sin\theta\, d\theta = -R_o\,P\cos\theta \Big|_{\theta}^{\alpha} \tag{4}$$

The exterior radius at $\theta$ then is:

$$r_1 = \left(\frac{\pi\,R_oM}{4E} + r_2^{\,4}\right)^{1/4} \tag{5}$$

The shape of the boot as described by Equation (5) assumes that the shape remains constant as a function of cable angle. For small angles (≈2 deg), this assumption is practical. However, for large angles, up to 25 deg, the shape must be adjusted for the distortion caused by compressing of one side of the boot and elongating the boot on the other side.

Poisson's ratio for the elastomers considered in this study varies predictably as a function of deformation. Tests were conducted on three elastomers to determine the relationship of the exterior radii at $\phi$ and at cable angle $\alpha$.

*The corrected radius is:*

$$r = 2.05 \left[ \frac{b^2 + (b^2 - 4ac)^{1/2}}{2a} \right]^{1/2} - 0.55 \, \frac{b^2 + (b^2 - 4ac)^{1/2}}{2a} - 0.09 \qquad (6)$$

Where:

$r$ = the initial outside radius to produce a final outside radius of $r_4$ based on Equation (5).

$$a = 6 R_o^2$$

$$b = r_4^2 - 12 R_o^2 r_1^2 - r_2^2$$

$$c = -(2 R_o^2 r_4^4 + 4 R_o^2 r_4^2 + R_o^2 r_2^4 - 6 r_2^4$$

$$r_4 = \left[ \frac{R_o \, (r_1^2 - r_2^2)}{R_o - \frac{(r_1^2 - r_1^2)^{1/2}}{2}} + r_2^2 \right]^{1/2}$$

The corrected radius was computed for stations located in integral degrees ($\theta$) with maximum cable angle of 25 deg. The computations were used to establish the shape of the TFB boot (Figure 2).

The inside radii are defined by the dimensions of the wire rope and the shank of the swaged fitting.

## DESIGN AND FABRICATION INSTRUCTIONS

The design and fabrication of termination boots should be accomplished in the following sequence:

- Define Design Parameters
- Select Material
- Determine Boot Envelope
- Fabricate Boot.

### Design Parameters

Once the cable diameter, tension, maximum bending angle, and minimum cable bend radius have been determined, the designer should determine if the application limits the physical size or shape of the boot. If the size and shape of the boot is affected, special consideration must be given to the material as discussed below.

## Material Selection

Virtually any material that meets the following definition of an elastomer may be used: an elastomer is any material that has a flexural modulus (E) of $\leqslant$ 2900 psi and elongation ($\Delta 1$) of $\geqslant$ of 150%. Inspection of the Design Theory calculation reveals that the size of the boot may be tailored to suit the application by selecting a material with the appropriate modulus. The lower the modulus, the larger the boot and vice versa. A high modulus is generally preferable since it results in a less bulky design, less material, and – depending on the material – usually a lower cost per boot. Another important consideration in material selection is the method of fabrication. High-quantity automated production will require a fast-curing material.* Prototype or limited-quantity manual production is best accomplished through casting, utilizing materials with long pot life. The Bibliography lists sources that will provide useful information on material selection.

## Boot Envelope

The calculations required to determine the boot envelope should be performed with the aid of a small computer or programmable calculator. Figure 4 provides the input sequence and program listing for an HP-65 programmable calculator.

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**Other manufacturing methods could be compression, injection, RIM (Reaction Injection Molding) molding, or casting. The method is dictated primarily by the mass and thickness of the sections of the boot.*

1. Clear Register

2. Data Input

| | Characteristic | Operation | Output |
|---|---|---|---|
| a. | Modulus of Elasticity, psi (E) | Enter | |
| b. | Rope Radius, inch ($r_2$) | Enter | |
| c. | Min. Bending Radius, inch ($R_o$) | Enter | |
| d. | Maximum Tether Tension, lb, (P) | A | |
| 3. | $\theta$ | B | Boot exterior radius at Station $\theta$, inches (r) |

4. Repeat for next $\theta$

PROGRAM

```
0000   3408     81     09     51     32     71   3305   3406     71
3304     31   3403     01   3306     09   3402   3405     61   3406
3508     05     71     02     02     71     04     02     01     32
3303     01   3402     41     41   3405     35     04     02     09
3508     51     04   3403   3403     32     05     71     81     83
3302     42     35     32     32     09     71   3403   3403     05
3508   3404     05     09     09     71     61     32     32     05
3301     71     61     71     71   3402     06     09     09     71
  24   3403     04   3402   3405     32     41     71     81     51
  23     71     35     32     04     09   3402     42     31     83
  12     35     04     09     35     71     04   3406     09     00
3308     02     35     71     05     61     35     32   3306     09
  22     71     05     51     71     02     05     09     02     51
  01     04   3305   3402     04     41     71     61     83     24
  23     81   3405     32     41   3403     51     31     00
  01   3401     32     09   3403     32     42     09     05
                                     09
```

Figure 4. Boot design program for HP 65 calculator.

As a further aid to potential users of this procedure, two additional sample designs have been included. Figures 5 and 6 illustrate two possible applications related to surveillance and underwater navigation systems. Unlike the TFB tether, these two applications involve an electromechanical cable. Figures 7 and 8 show the design resulting from the program shown in Figure 4. These two examples plus the TFB boot (Figure 3) should give potential users of these procedures a good idea of variance in boot size for different design parameters.

## FABRICATION INSTRUCTIONS

Once the envelope of the boot is determined, a mold may be constructed. Note that (see Figures 7 and 8) the non-defined portion of the boot should be at least four times as long as the largest radius calculated. (See Figure 7 and 8.) Design of the base of the boot is open to whatever is required by the application as long as the diameter is $\geqslant 2r$. In order to prevent a gap at the point where the cable exits the boot, a retaining collar must be applied at that end of the boot. The collar should be constructed of Nylon-11 or equivalent and in accordance with Figure 9. Note the retaining ridge (Figure 9, Detail A) is required to insure that the retaining collar remains seated on the end of the boot. Once properly installed, the collar is not removable and must be cut away if removal is desired.

Sources listed in the Bibliography provide information regarding fabrication of the mold, handling of materials, and molding methods.

Once the boot has been molded, the following general procedure should be followed. See Figure 10.

1. Slip the retaining collar onto the end of the boot, approximately 1/8 inch.
2. Lubricate the cable with petroleum jelly or silicon grease.
3. Slide the boot onto the cable using a rotating motion.
4. Press the retaining collar flush with the end of the boot.
5. Install the cable and fitting connect or termination.
6. Using a slotted bearing plate, apply tension to seat the boot over the connector, termination or end fitting.
7. If desired, pot the base of the retaining boot to seal it to the connector, termination, or end fitting.

Depending on the application, this procedure may vary.

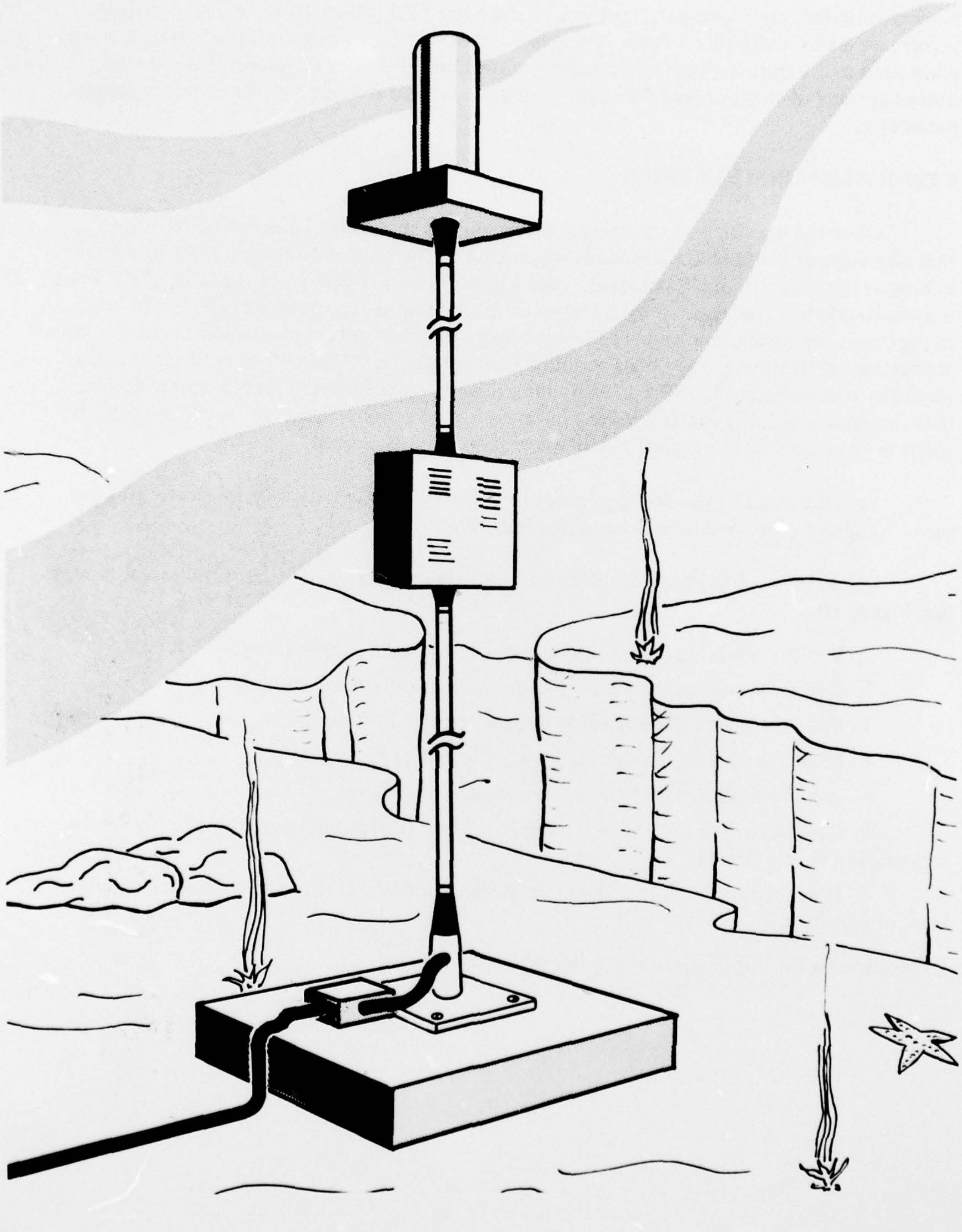

Figure 5. Typical bottom-mounted array configuration.

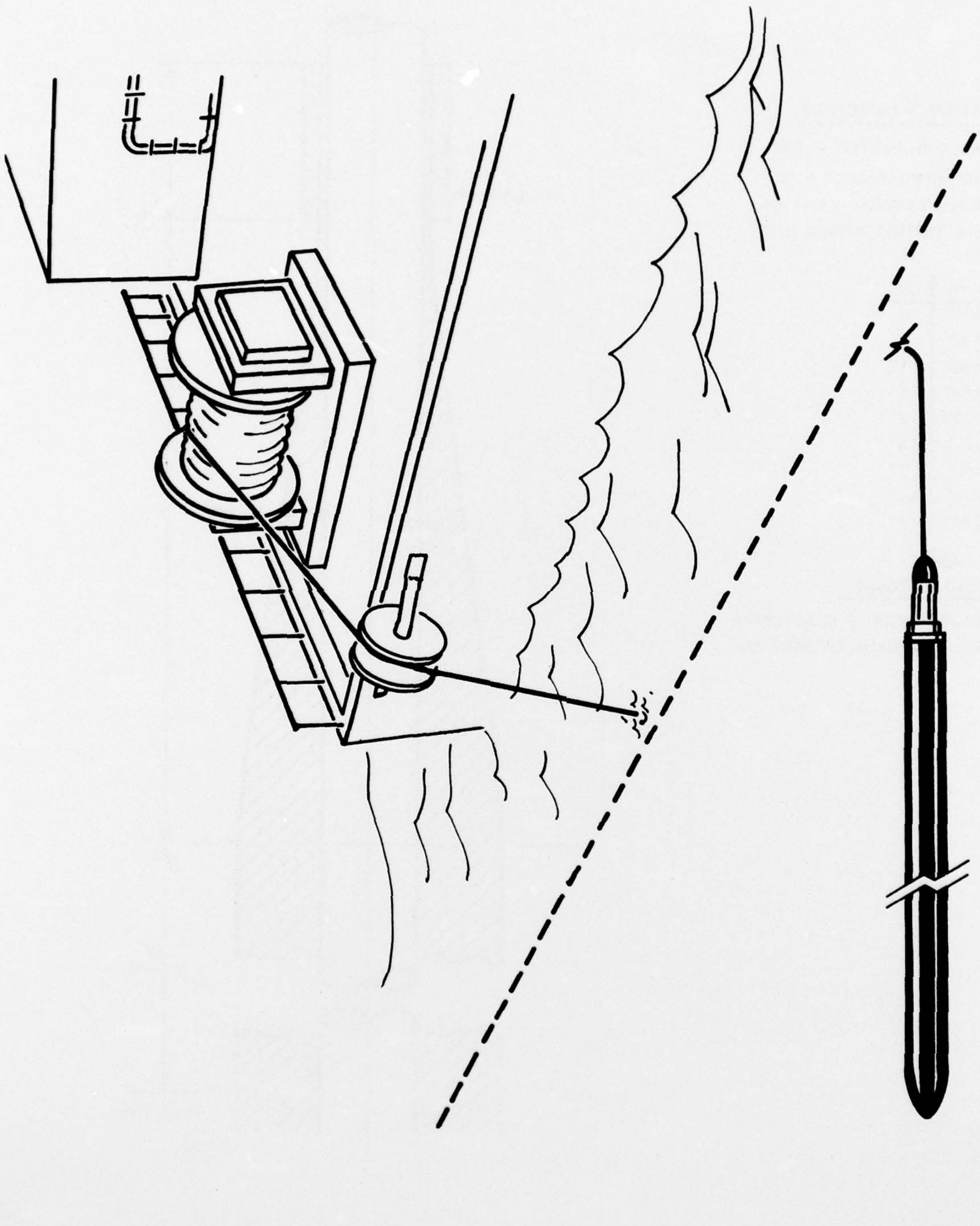

Figure 6. Typical towed array configuration.

DESIGN PARAMETERS

CABLE DIAMETER = .625"
MIN. BEND RADIUS = 12"
CABLE TENSION = 600 lbs.
MAX TETHER ANGLE = $10^{\circ}$

| Y (r) | X |
|---|---|
| 0.35" | 0 |
| 0.38" | .5" |
| 0.45" | 1" |
| 0.52" | 1.5" |
| 0.60" | 2" |
| 0.67" | 2.5" |
| 0.73" | 3" |
| 0.79" | 3.5" |
| 0.84" | 4" |

BOOT MATERIAL

POLYURETHANE ELASTOMER
WITH MODULUS OF 2800 PSI

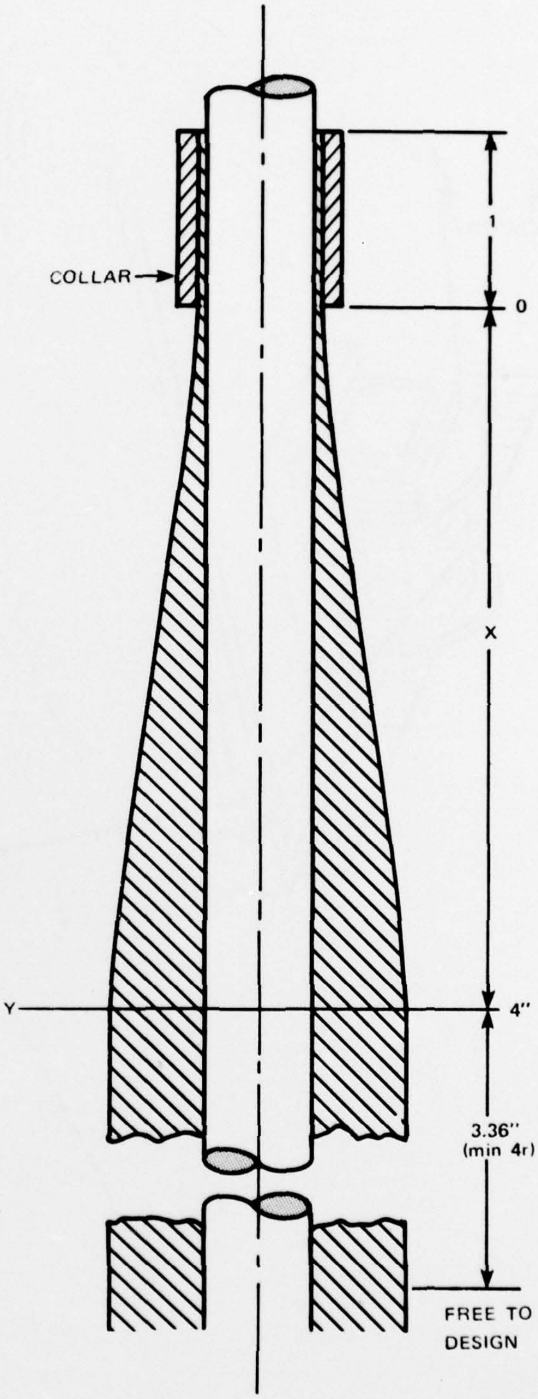

Figure 7. Boot design for typical bottom-mounted array configuration.

DESIGN PARAMETERS

CABLE DIAMETER = 1"
MIN BEND RADIUS = 24"
CABLE TENSION = 1000 lbs.
MAX TETHER ANGLE = $10^{\circ}$ STOWED
MAX TETHER ANGLE = $2^{\circ}$ DEPLOYED COLLAR

| X (r) | X |
|---|---|
| 0.58" | 0" |
| 0.73" | .5" |
| 0.94" | 1" |
| 1.11" | 1.5" |
| 1.25" | 2" |
| 1.36" | 2.5" |
| 1.45" | 3" |
| 1.52" | 3.5" |
| 1.58" | 4" |

BOOT MATERIAL

POLYURETHANE ELASTOMER
WITH MODULUS OF 2800 PSI

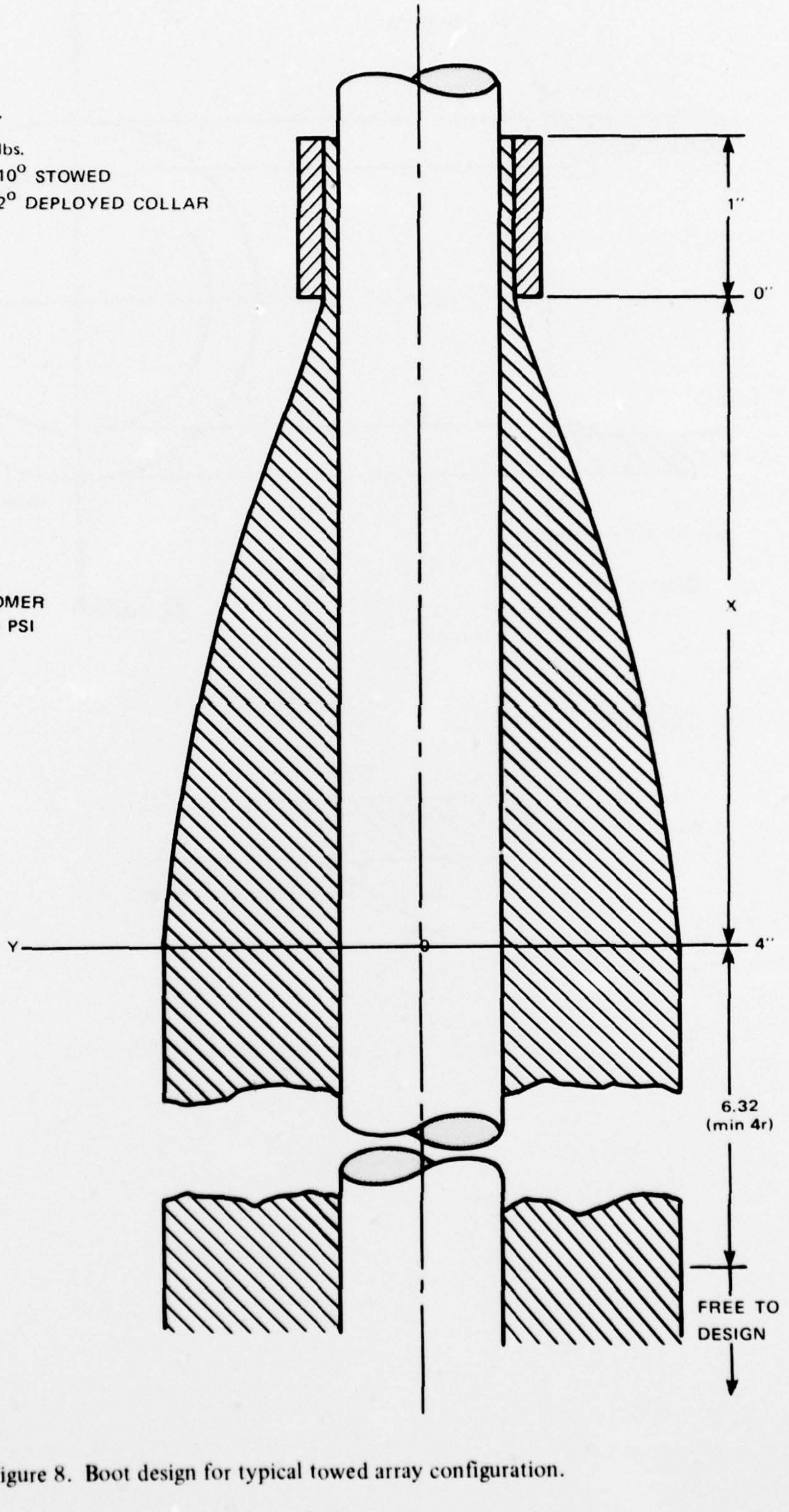

Figure 8. Boot design for typical towed array configuration.

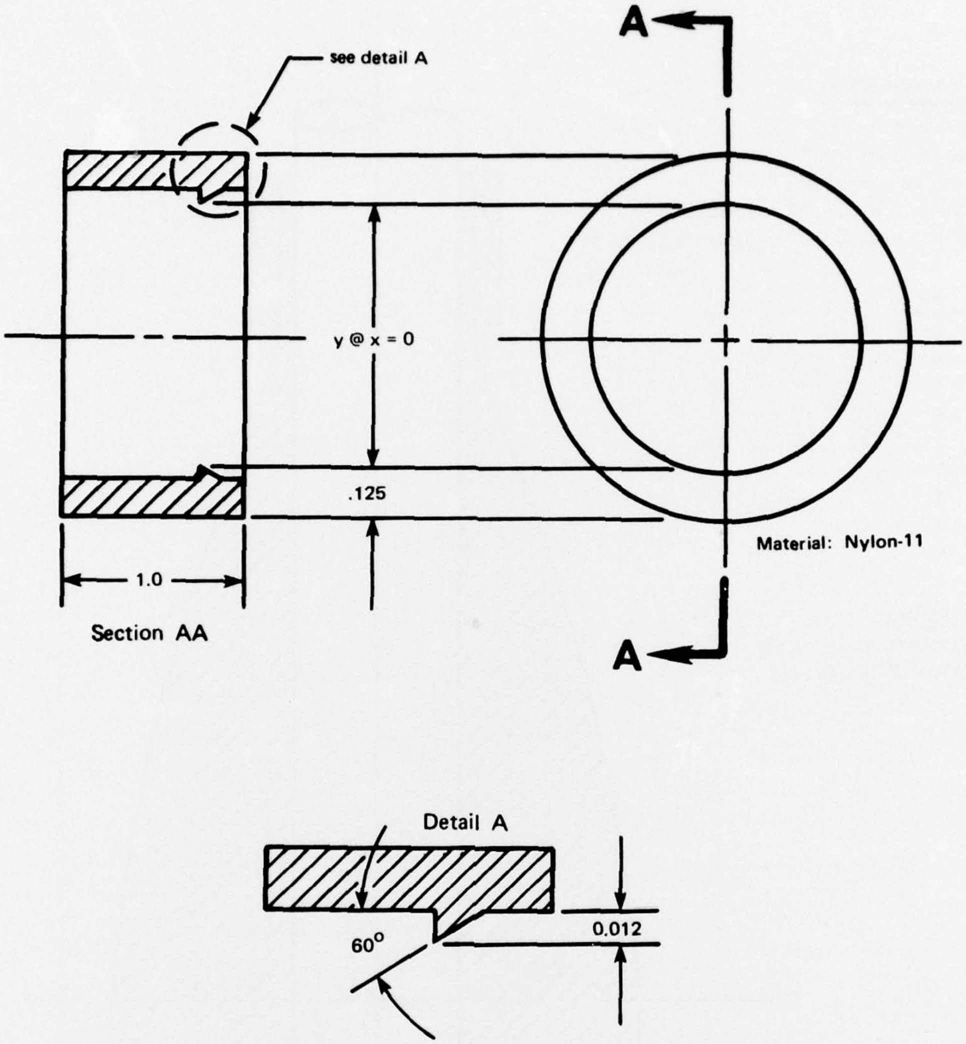

Figure 9. Termination boot retaining collar.

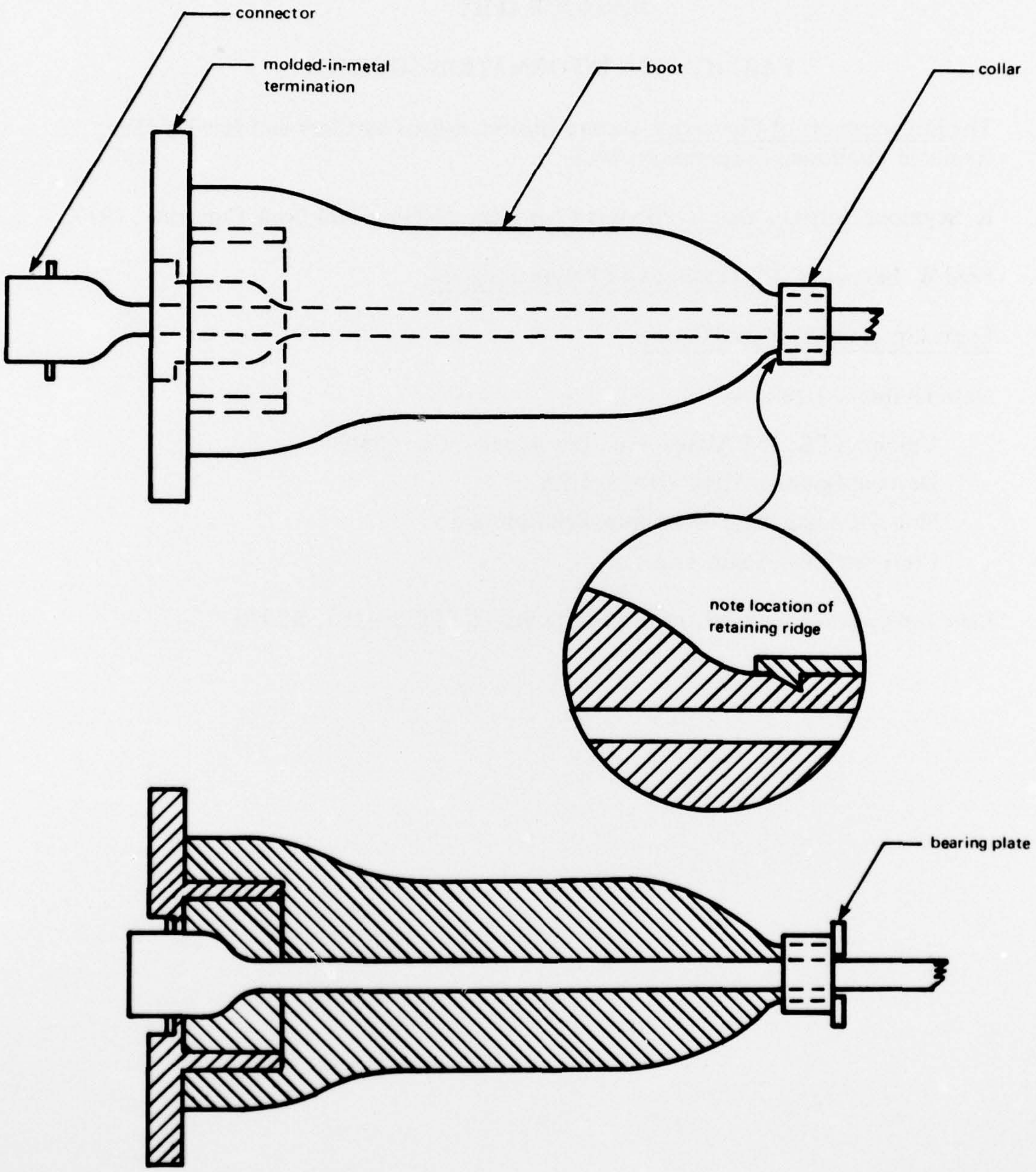

Figure 10. Assembly of typical electromechanical termination boot.

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